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13. SUPPLEMENTARY NOTES Viewgraph Presentation for the American Physical Society, San Diego, CA in 18-20 November 2012.					
14. ABSTRACT This research establishes multi-phase molecular tagging velocimetry (MTV) use and explores its limitations. The flow conditions and geometry in the inducer of an upper stage liquid Oxygen (LOX)/LH2 engine frequently cause cavitation which decreases turbopump performance. Complications arise in performing experiments in liquid hydrogen and oxygen due to high costs, high pressures, extremely low fluid temperatures, the presence of cavitation, and associated safety risks. Due to the complex geometry and hazardous nature of the fluids, a simplified throat geometry with water as a simulant fluid is used. Flow characteristics are measured using MTV, a noninvasive flow diagnostic technique. MTV is found to be an applicable tool in cases of low cavitation. Highly cavitating flows reflect and scatter most of the laser beam disallowing penetration into the cavitation cloud. However, data can be obtained in high cavitation cases near the cloud boundary layer.					
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Validity of Molecular Tagging Velocimetry in a Cavitating Flow for Turbopump Analysis

19 November 2012



Kayla Kuzmich
Doug Bohl, Ph. D.

Clarkson University
Potsdam, NY

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Outline



- **Objectives**
- **Flow diagnostic**
 - Molecular tagging velocimetry
- **Facility and experimental design**
 - Deaeration system
 - Cavitating test section
- **Test points**
- **Results**
- **Conclusions**



Objectives



- **Develop data necessary to calibrate cavitation codes**
- **Explore the application of MTV in two phase flow**
- **Explore the fluid dynamics of the model**



Molecular Tagging Velocimetry (MTV)



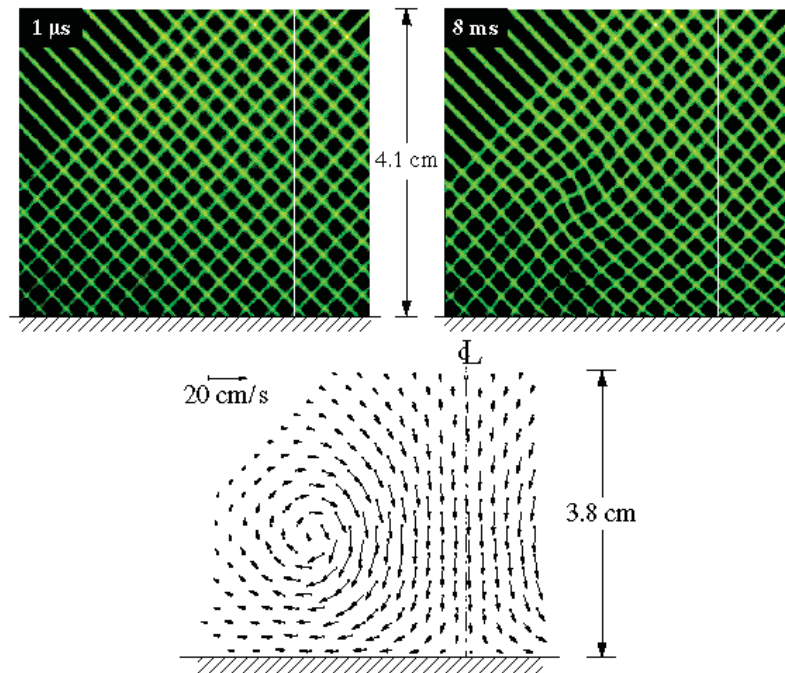
- **Whole field, non-intrusive, optical technique**
- **Tracer uniformly mixed with working fluid**
 - Measurements possible everywhere
 - Tagged region imaged twice during life time of tracer
- **Long lived tracer excited (tagged) at proper wavelength**
 - Phosphorescence
 - Quenched by oxygen
- **Velocity is the derivative of the Lagrangian displacement**



Molecular Tagging Velocimetry



- **Triplex - $\tau=3.5\text{ms}$**
 - Bromonaphthalene – Saturated [$\sim 10^{-5}\text{ M}$]
 - Cyclodextrin – [10^{-4} M]
 - Cyclohexanol – [0.055 M]



MTV grid at two different times and the resultant velocity field



Facility Design

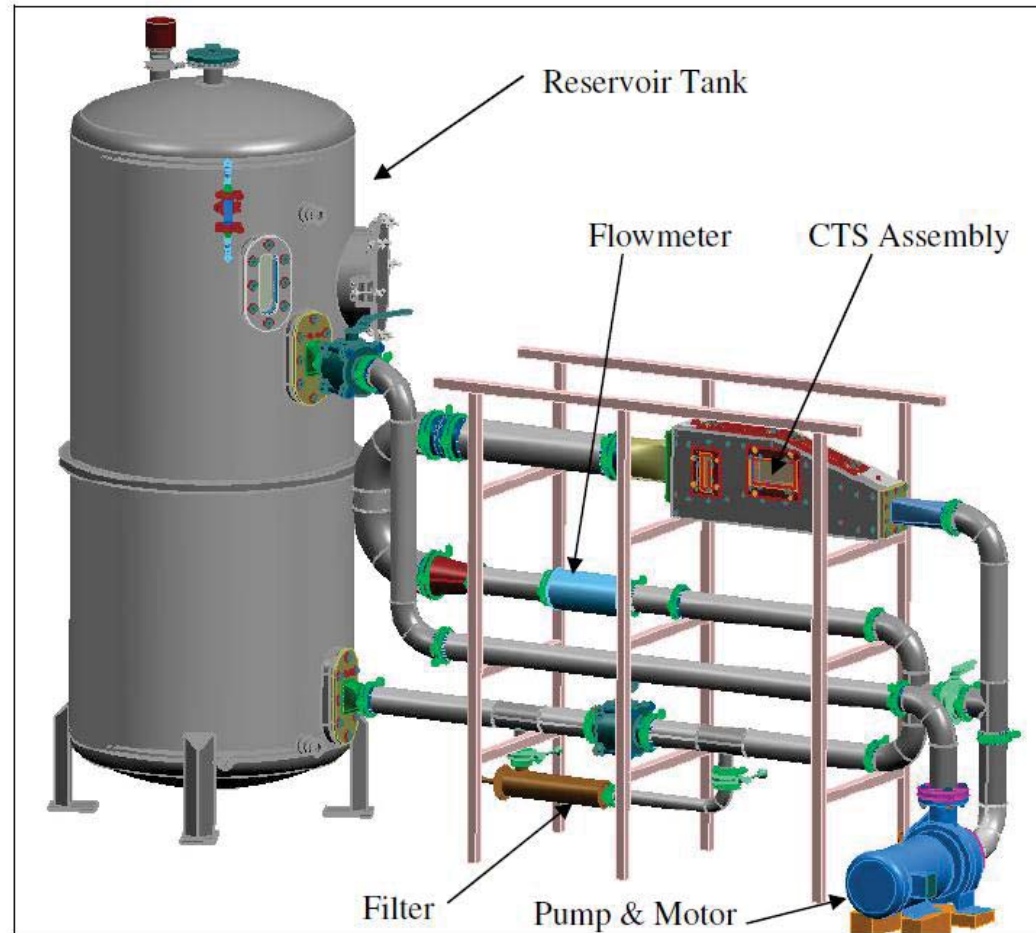
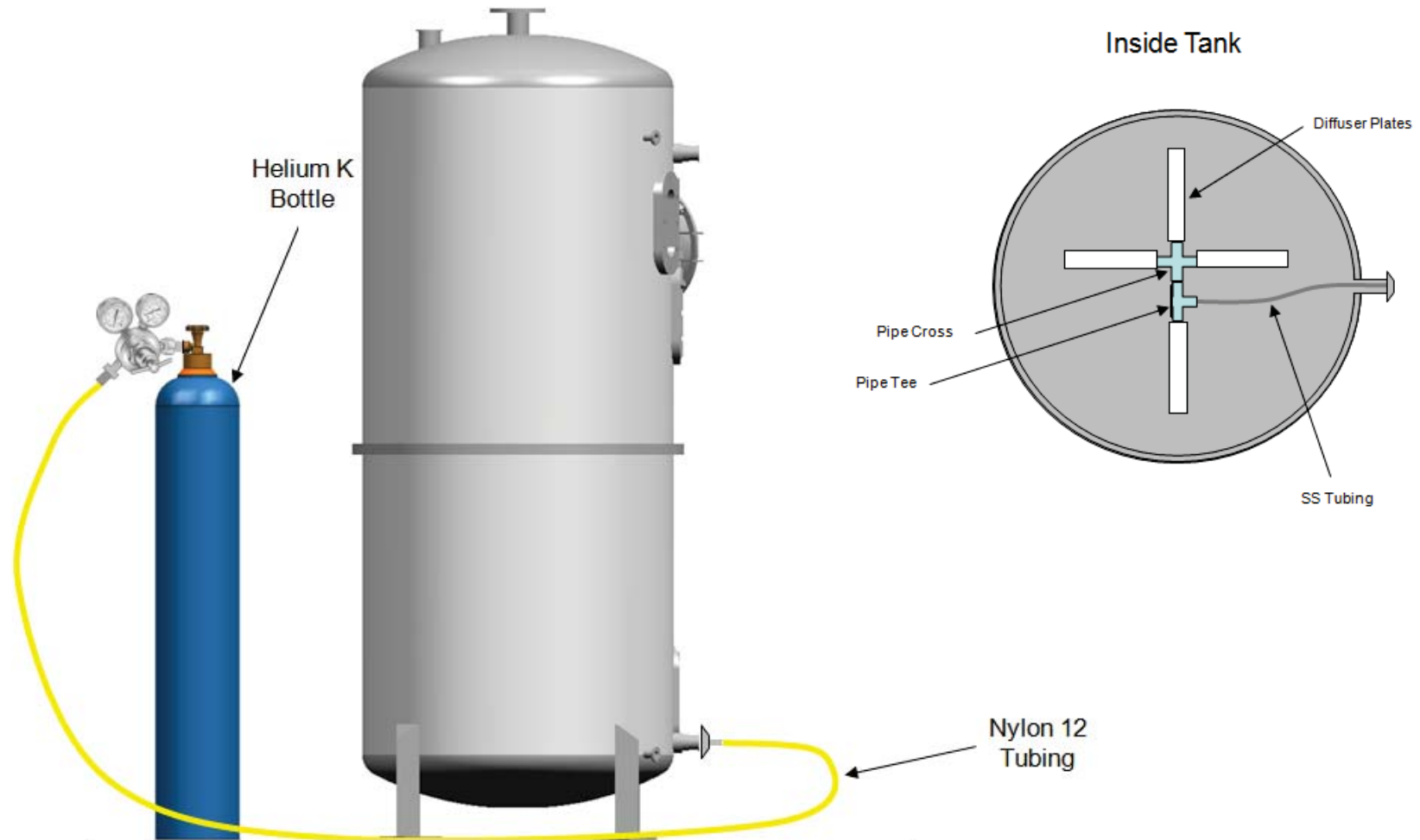


Figure 5: Facility Model



Deaeration System



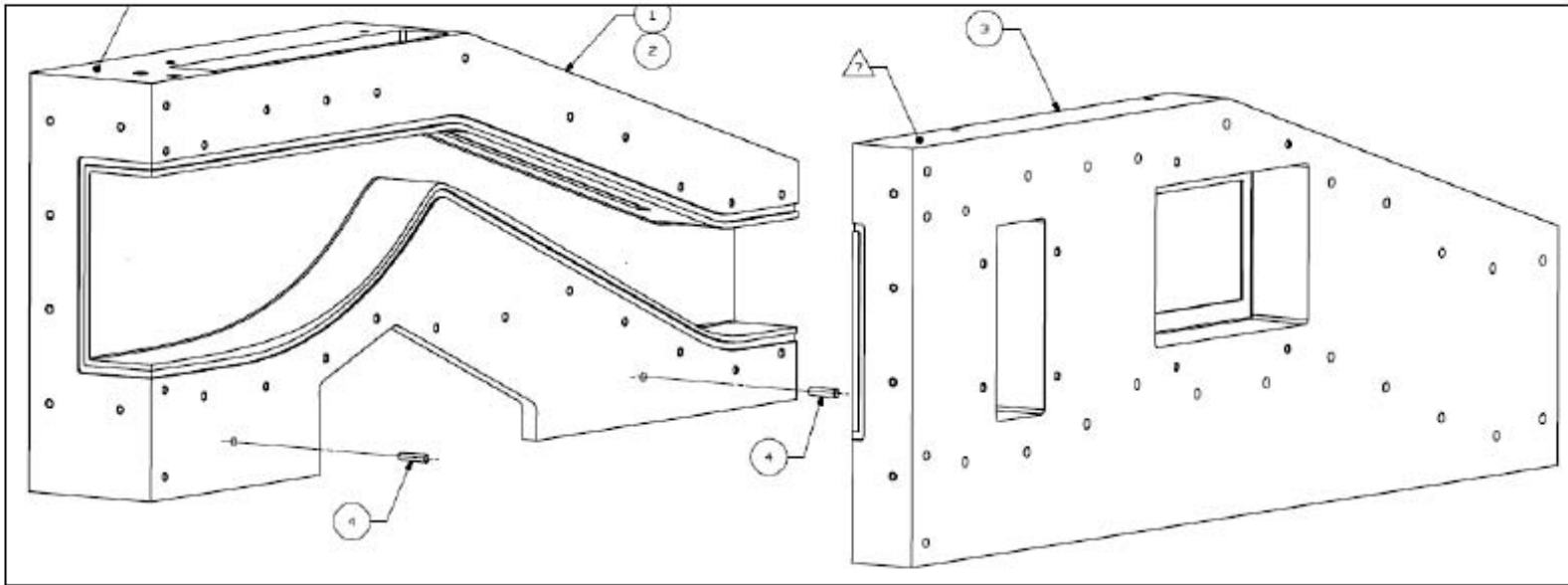
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Cavitating Test Section (CTS)



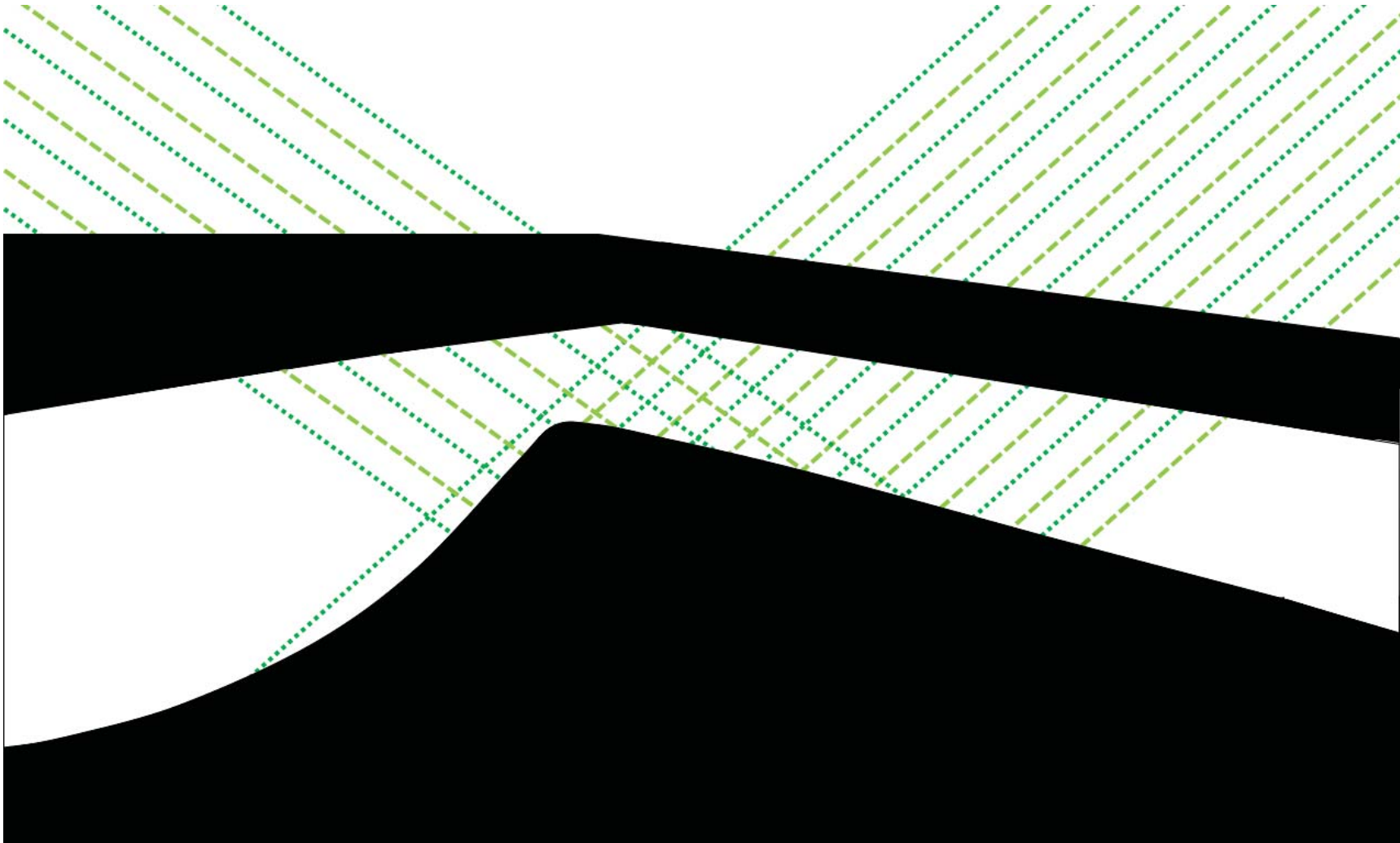
- 25" long CTS
- Two slits on the top surface
- Black anodized aluminum



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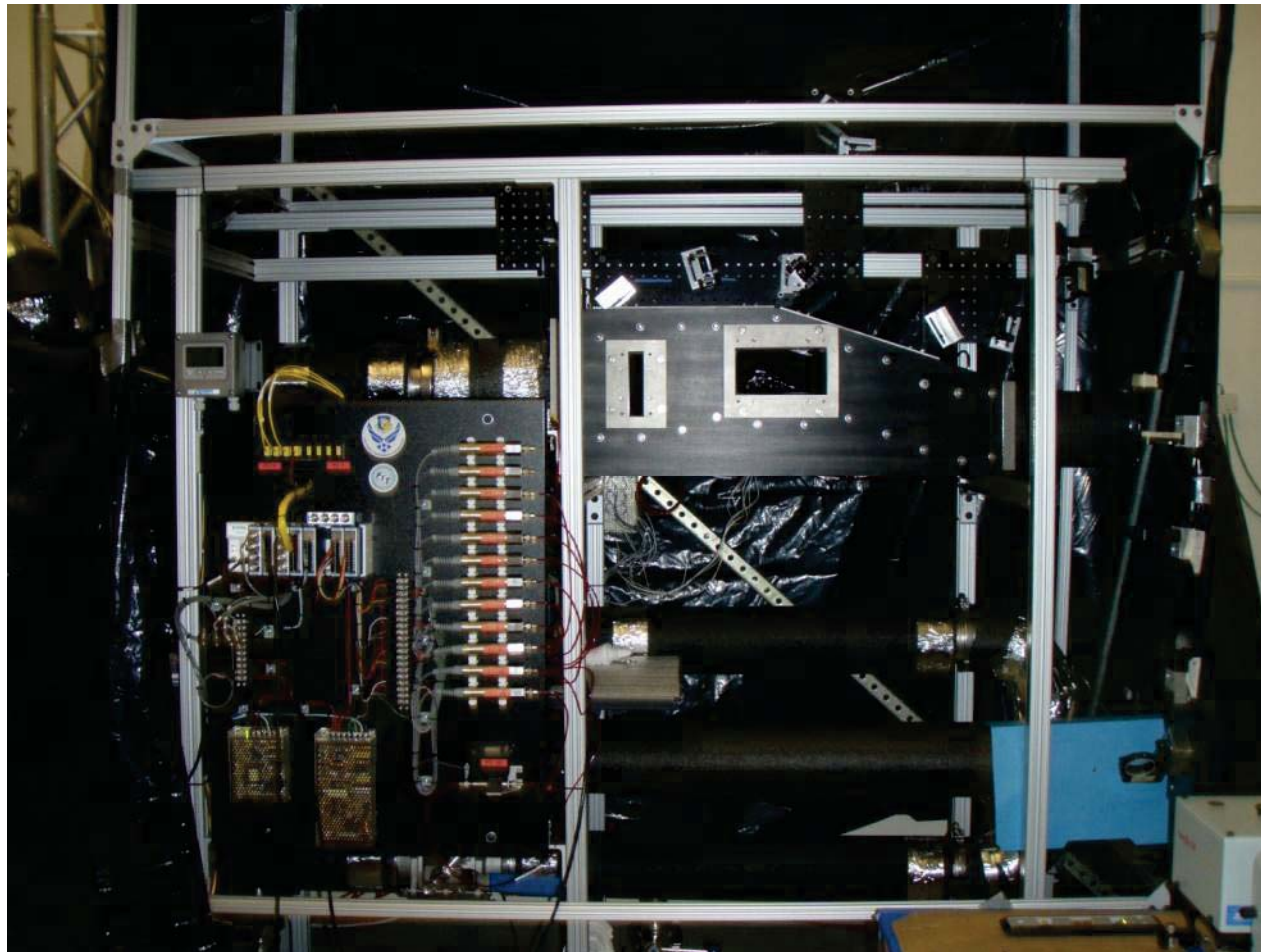
CTS with Laser Grid



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Experimental Set-up



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Experiment

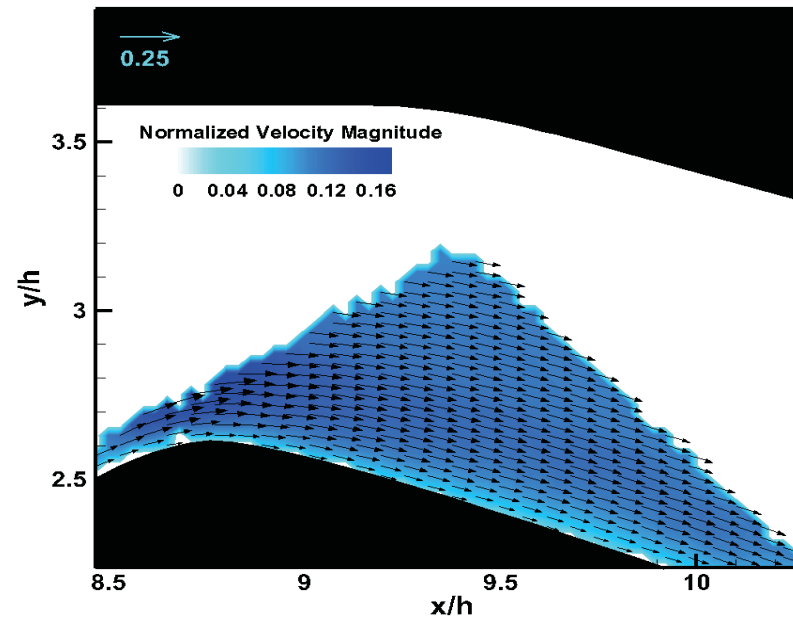
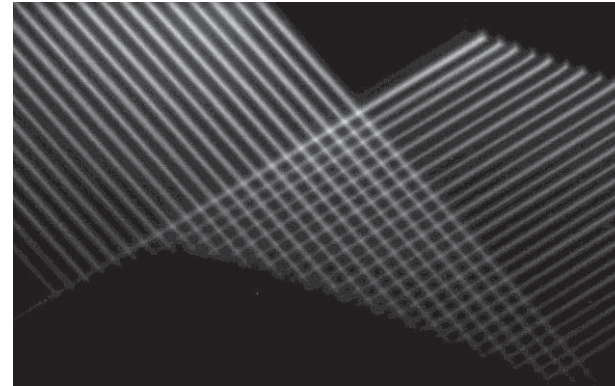
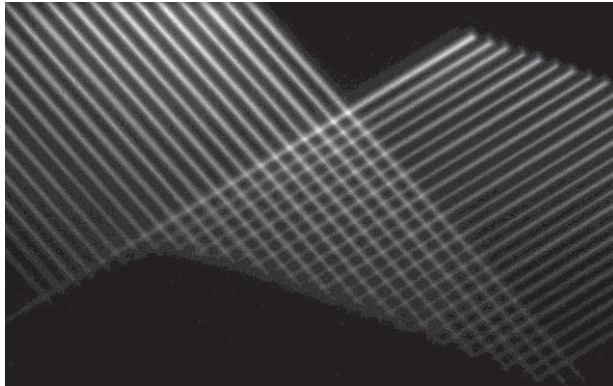


- **20 runs of each test point**
 - Volumetric flow rate
 - Ten offset
- **209 images for each run**
- **Test points**
 - 3 non-cavitating
 - 1 inception of cavitation
 - 3 fully cavitating

Test Point	Flow Rate [gpm]
1.0	326
1.1	354
1.2	377
1.3	388
1.4	398
1.5	409
1.6	430



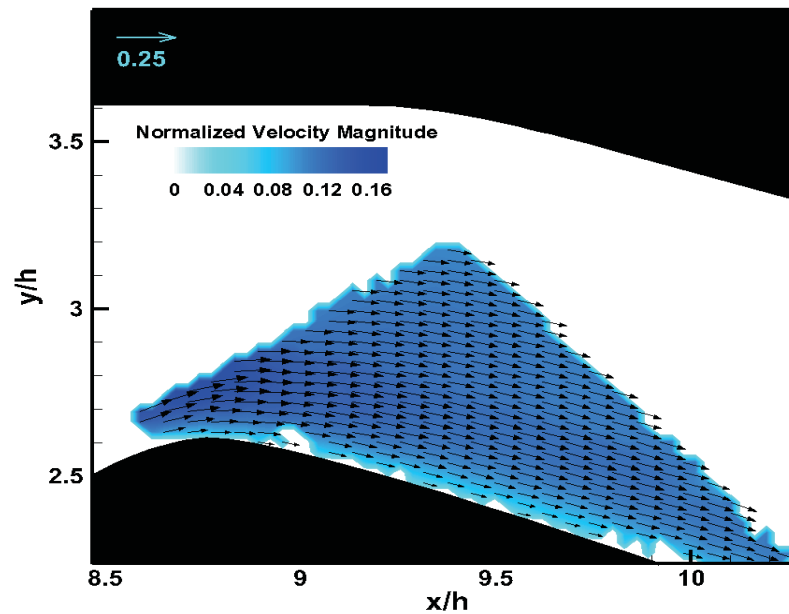
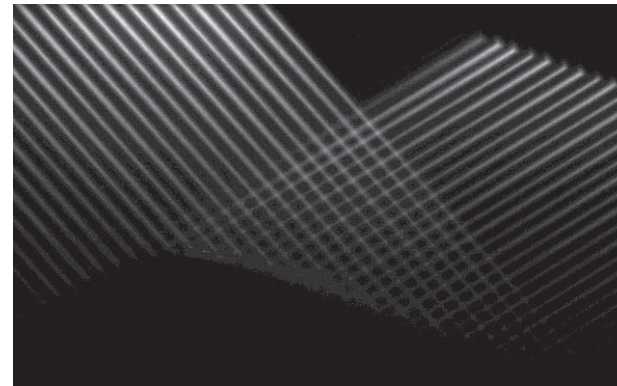
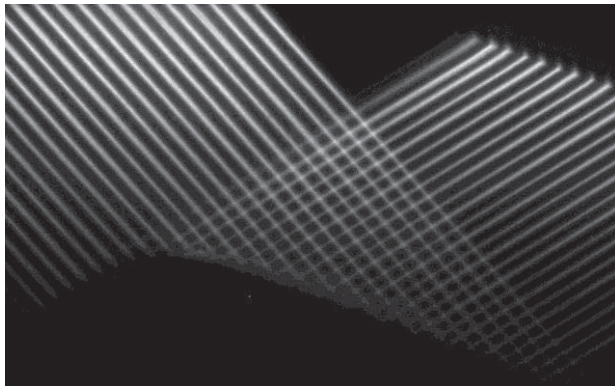
Non-cavitating (Point 1.2)



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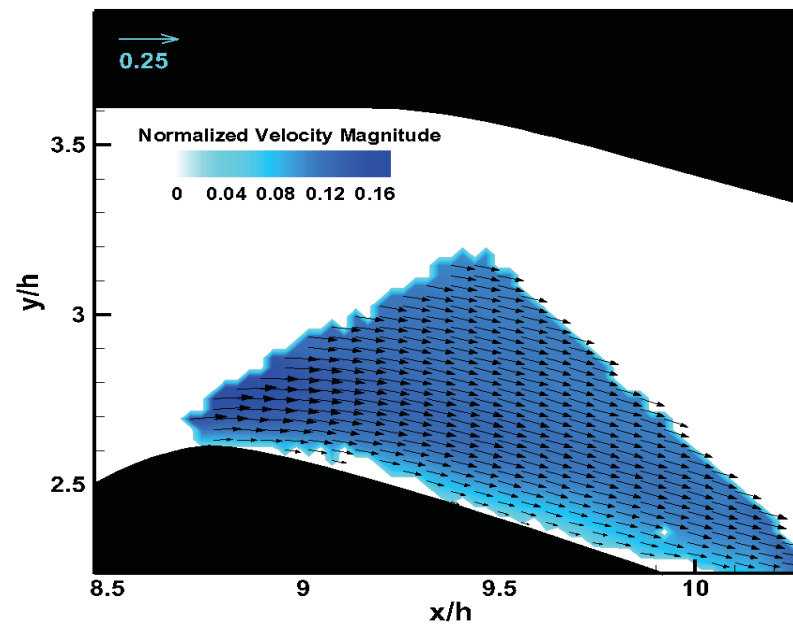
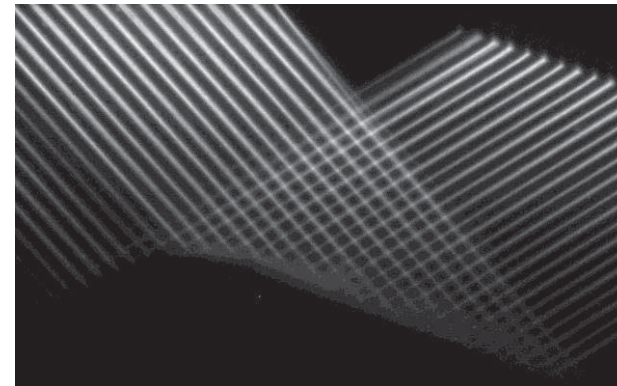
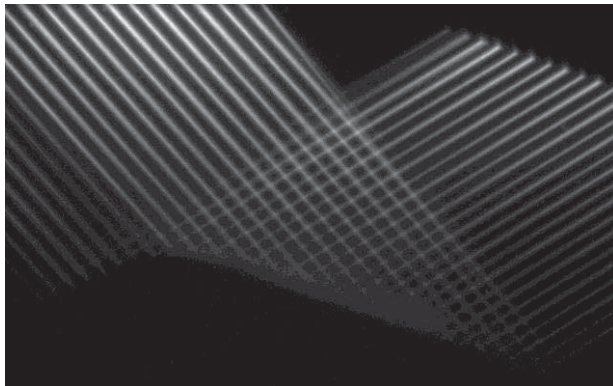
Light Cavitation (Point 1.3)



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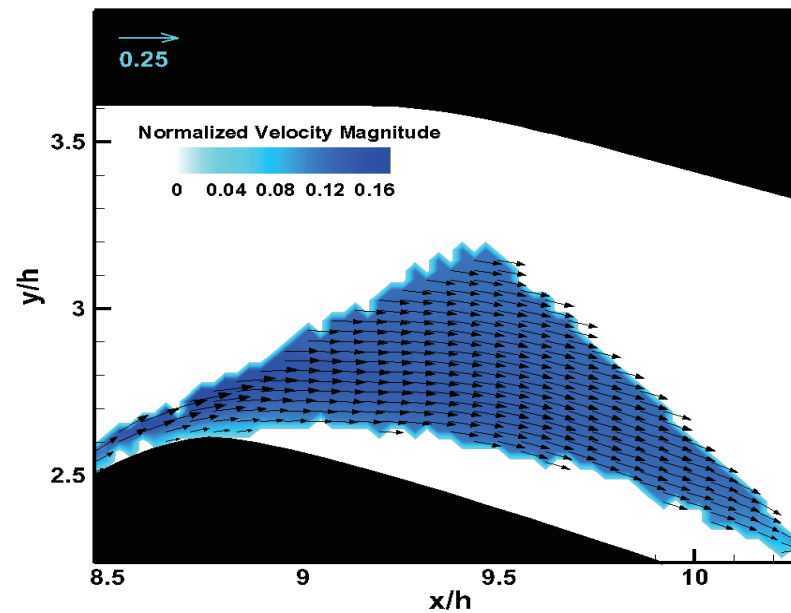
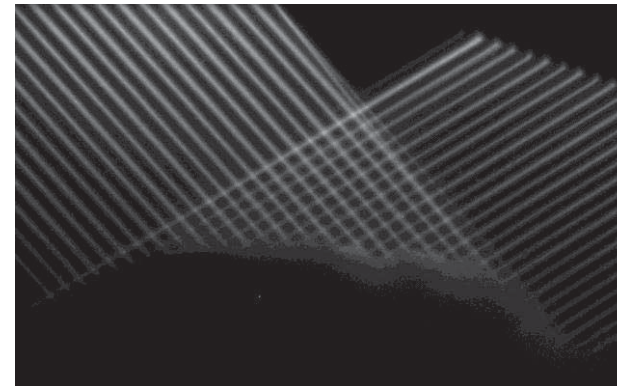
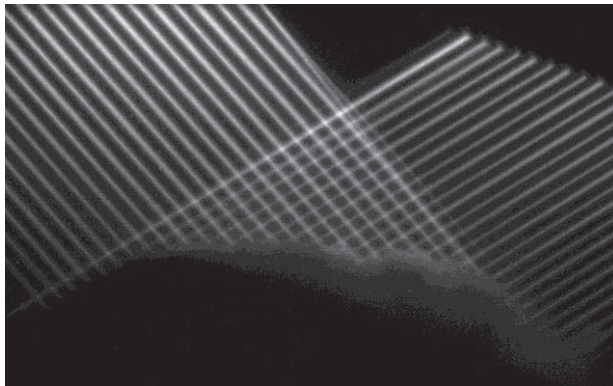
Moderate Cavitation (Point 1.4)



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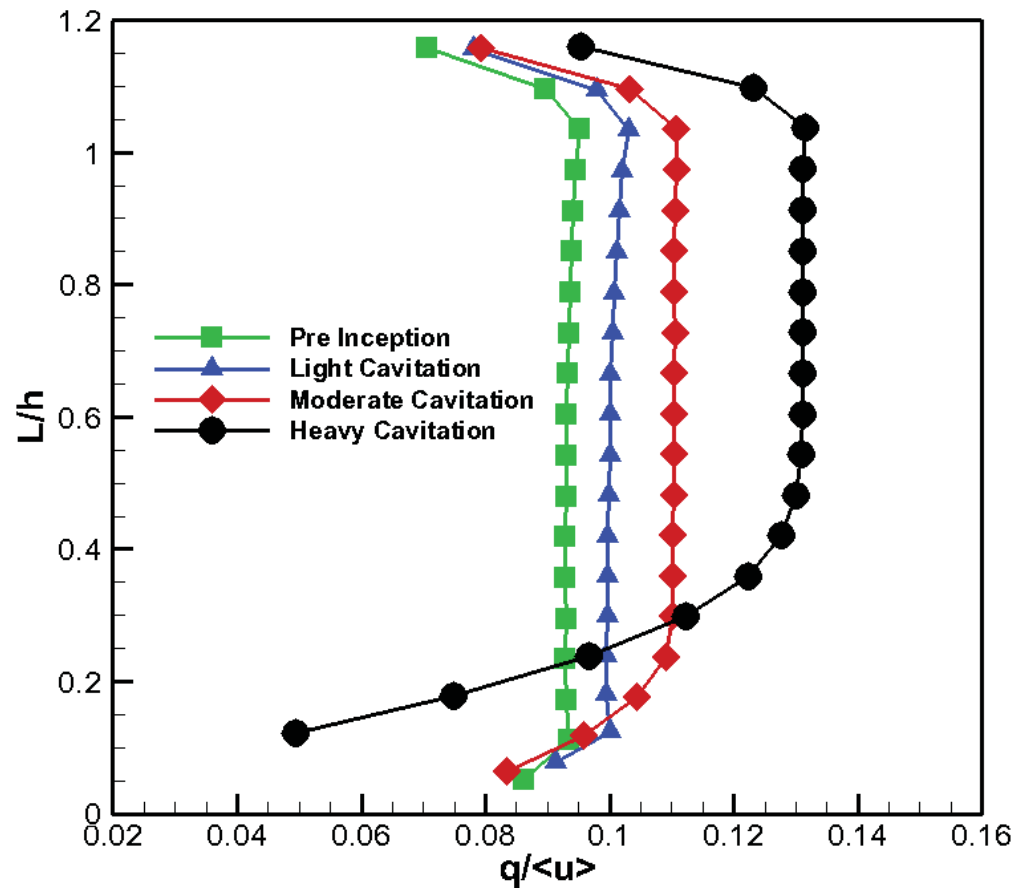
Heavy Cavitation (Point 1.6)



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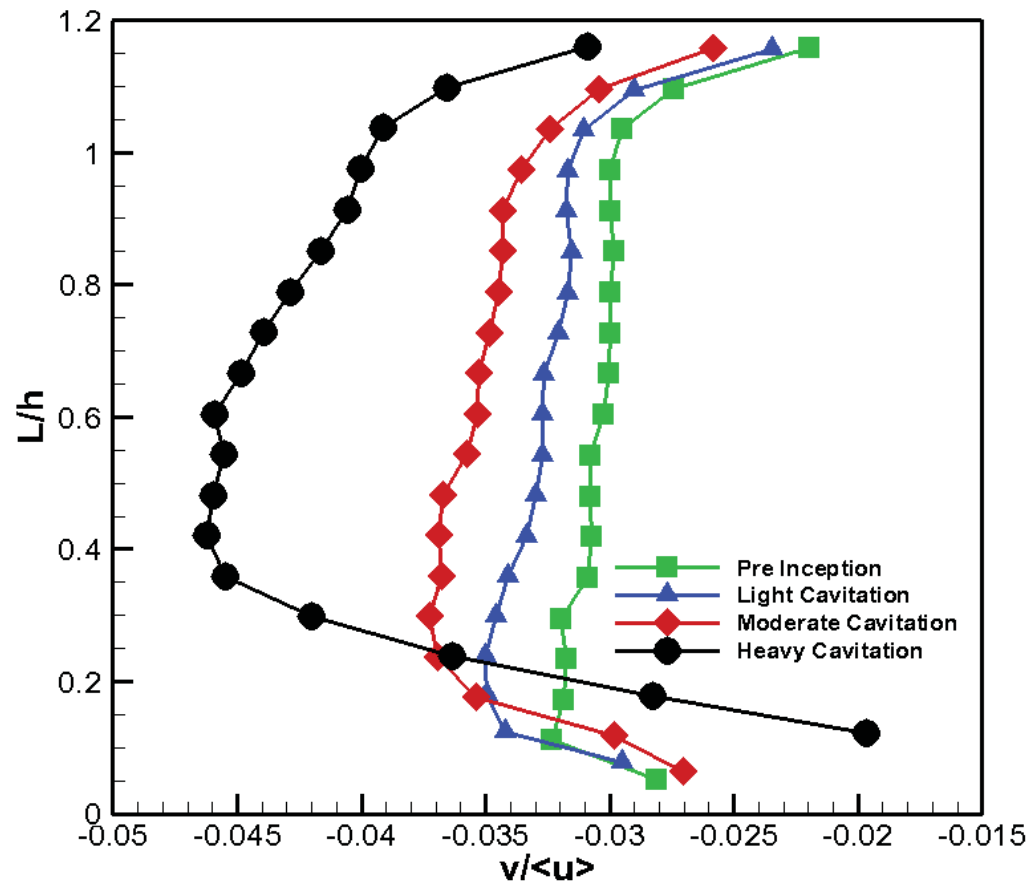
Normalized Velocity Profiles



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Normalized v-Velocity Profiles



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Conclusions

- **Data was used to aid in cavitation number calibration**
- **MTV was successfully used in two phase flow**
 - Though the limits of use were established based on cavitation cloud density
- **Velocity at the throat increased with increased cavitation**